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The Hall effect for silver

Verifying the proportional relationship between Hall voltage U_H and magnetic flux density B, determining the polarity of the charge carriers which are mainly responsible for charge transport in silver. Calculating the charge carrier density *n*.

If a current-carrying metallic conductor band is in a magnetic field perpendicular to the direction of current, a transverse electrical field and a potential difference are produced (Hall effect).

The following equation is valid for the Hall voltage U_H:

$$U_H = \frac{1}{n \cdot e} \cdot \frac{B \cdot I}{d} \qquad (1)$$

B: Magnetic flux density
I: Current
d: Thickness of the band-shaped conductor
e: Elementary charge
n: Concentration of charge carriers

$\frac{1}{n \cdot e}$ is called the Hall constant R_H. R_H is a value which is dependent on material and temperature:

$$R_H = \frac{1}{n \cdot e} \qquad (2)$$

(2)

The conductor band consists of silver in the following experiment. First, it will be proved that $U_H \sim B$.

The polarity of the charge carriers which are mainly responsible for the current (polarity of the Hall constants) can be determined from the direction of the Hall voltage. The concentration of the charge carriers is established experimentally since all the values in "1" except for n can be measured. The Hall voltage U_H is caused by deflection of the moving charge carriers in the magnetic field by the Lorentz force, whose direction may be predicted by the "right-hand rule".

Apparatus:

1	Hall effect apparatus, silver	586 81
1	U-core with yoke	562 11
1	Clamping device	562 12
1	Pair of bored pole pieces	560 31
2	Coils, 250 turns	562 13
1	Extra-low variable transformer	522 39
2	Interchangeable scale demonstration meters, basic units	530 50
1	Measuring module 0 to 1000 mT/3000 mT	530 75
1	Measuring module 0-3 A/10 A	530 65
1	Shunt resistor 30 A	530 90
3	Connecting leads, red, 50 cm	501 25
2	Connecting leads, blue, 50 cm	501 26
3	Connecting leads, black, 50 cm	501 28
1	Connecting lead, black, 25 cm	501 23
1	Microvoltmeter	532 13
1	Pole probe	516 501
1	Power supply unit 0-12 V/20 A, regulated	522 47

Recommended:

1	Calibrating magnet for pole probe ...	516 53
1	Multimeter 2H (15 A -)	531 53
2	Batteries 1.5 V/IEC R6	685 44

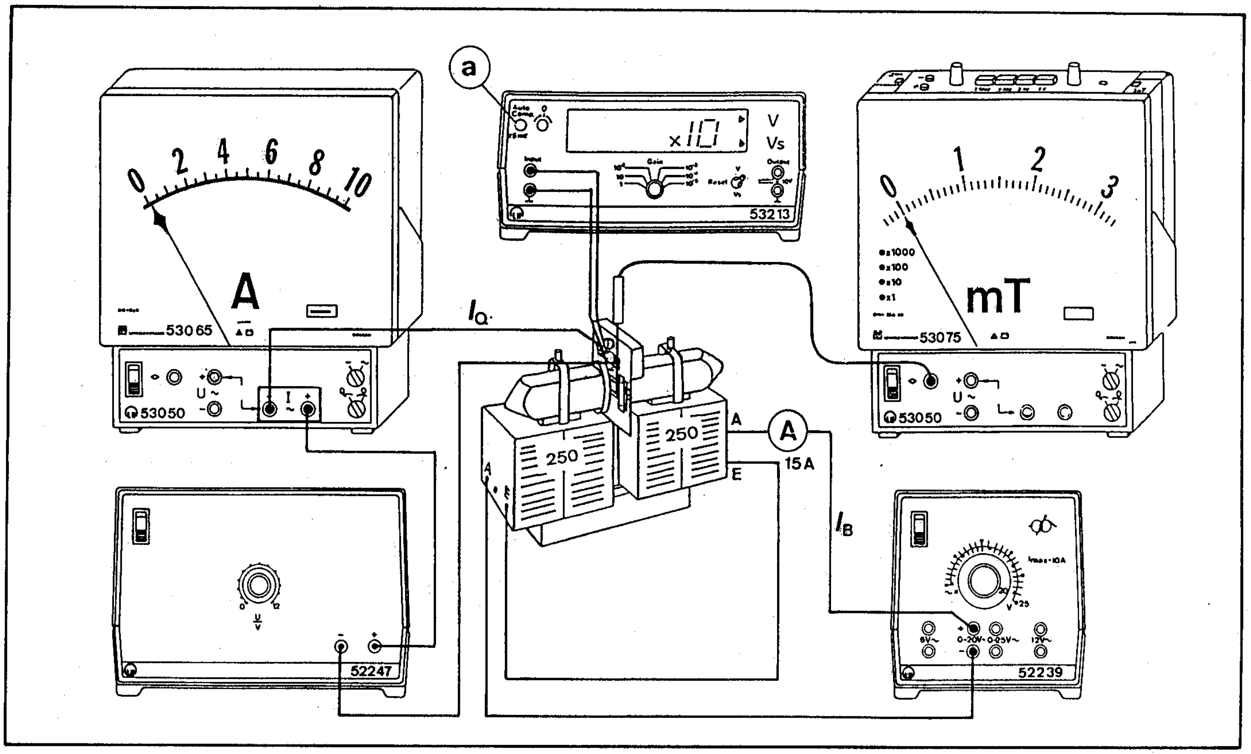


Fig. 1: Experiment setup for the Hall effect.
I_B: Field current

I_Q: Transverse current

Setting up:

Note:
Only switch on circuits for a short time for a transverse current above 15 A or magnetic currents above 5 A because the connecting leads will heat up and the coils designed for 5 A will overload.

In the transverse circuit, use leads which permit a load of 20 A (e.g. connecting leads 501 20-29 or safety connecting leads 500 65-74).

Set up the apparatus as in Fig. 1, initially without the Hall effect apparatus. Set up the electromagnet with exactly the pole piece spacing that is given by the thickness of the support plate of the Hall effect apparatus. To do this, loosen the clamping device and place one edge of the Hall effect apparatus between the pole pieces. Then push the latter as close as possible to the support plate.

Calibrate the Hall probe with the calibrating magnet as described in the instructions for use 516 501. Remove the protective sleeving from the pole probe.

Carrying out the experiment:

a) I_B - B calibrating curve:

Demagnetize the iron of the electromagnets before recording the I-B calibrating curve and before determining B from this curve (allow 5 A ∿ to flow through the coils for a short time).

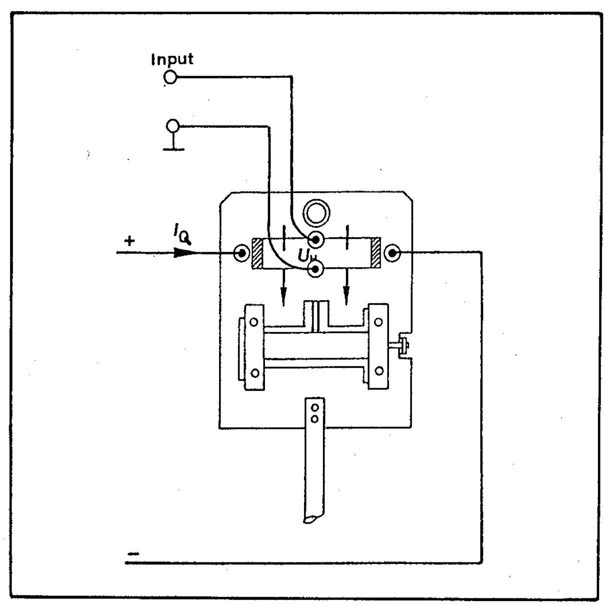
Measure the magnetic flux density B as a function of magnetic current I_B; to do this, increase I_B in steps of 0.5 A (Fig. 3).

b) U_H is a function of B for constant transverse current I_Q:

Mount the Hall effect apparatus in the electromagnet as shown in Fig. 1, with the pole pieces pushed as close as possible to the support plate (air gap as narrow as possible and of the same width as for the recording of the calibrating curve).

Connect the Hall effect apparatus to the microvoltmeter and the power source as shown in Fig. 2. The field direction should be as printed on the support plate (current direction I_B; coil connections).

Fig. 2: Electrical connections of the pole effect apparatus; I_Q: transverse current.



Reset the measuring instrument display for the Hall voltage U_H to zero before switching on the magnetic current I_F, but with the transverse current switched on. Correct the zero point by means of button (a) (Fig. 1) on the microvoltmeter.

After switching off the magnetic current, check the zero point again and, if necessary, take into account any fluctuations which have occurred.

Read off the respective zero voltage U_H for each set current I_B. Read off the effective field strength from the I_B-B calibrating curve for each current I_B. Transverse current I_Q = 15 A and I_Q = 20 A (Fig. 4).

Polarity of the charge carriers:

To determine the polarity of the Hall voltage for the chosen current direction.

Determination of the charge carrier concentration n and Hall constant R_H:

Set a transverse current I_Q = 15 A, and a field current I_B = 8.5 A (≙ B = 0.805 Tesla, in accordance with calibrating curve). Measure U_H.

Repeat measurement for I_Q = 20 A, I_B = 8.5 A.

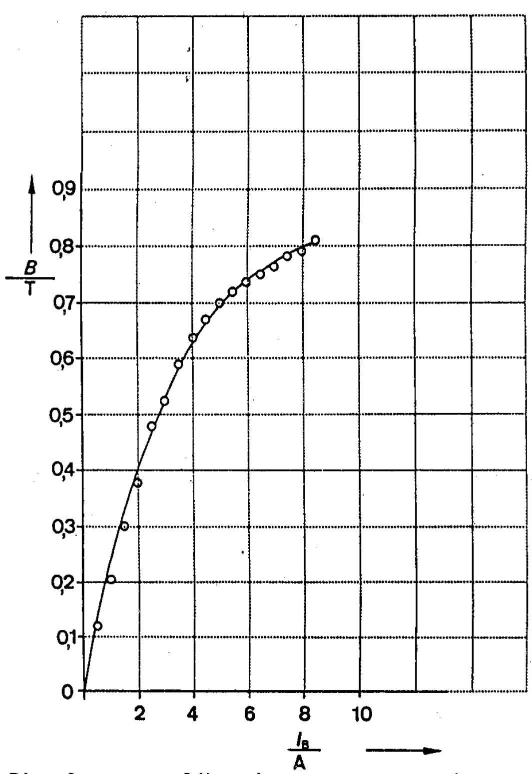


Fig. 3: I_B-B calibrating curve; pole piece distance the same as the thickness of the support plate
I_B: Coil current

B: Magnetic flux density of the field produced by I_B. Saturation at large field currents.

Measurement example:

a) Table 1/Fig. 3

Table 1:

I in A	B in T
0	0
0,5	0,118
1	0,200
1,5	0,295
2	0,374
2,5	0,455
3	0,520
3,5	0,585
4	0,630
4,5	0,665
5	0,695
5,5	0,715
6	0,735
6,5	0,748
7	0,760
7,5	0,780
8	0,790
8,5	0,800
9	0,810

b) Fig. 4

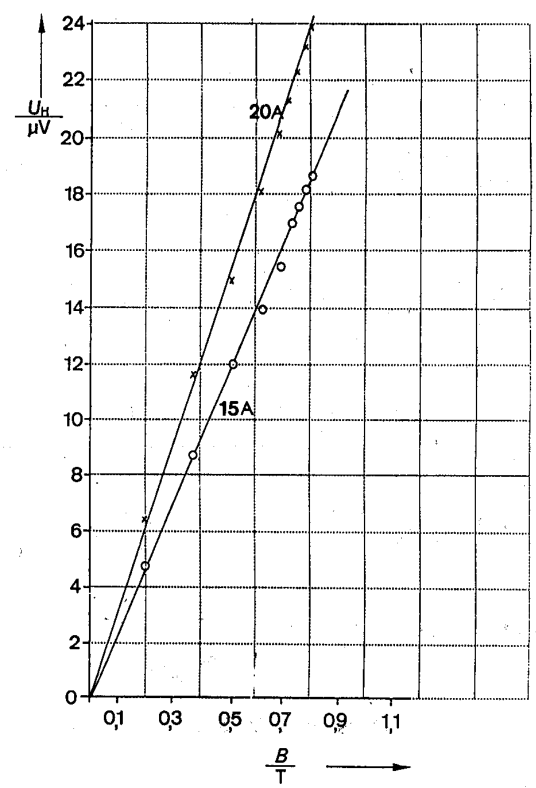


Fig. 4: U_H as a function of B; parameter I_Q

B in accordance with calibrating curve in Fig. 3 from I_B;

Hall foil made of silver.

c) The microvoltmeter indicates negative voltage values for the setup chosen in Fig. 2. The upper side of the Hall foil is thus charged negatively with respect to the lowest side.

d_1):

I_Q = 15 A; B = 0.805 T; foil thickness d = $5 \cdot 10^{-5}$m;

10^{-5} m;

e = $1.602 \cdot 10^{-19}$ C: $U_H = 1.87 \cdot 10^{-5}$ V.

d_2):

I_Q = 20 A; B = 0.805 T; $U_H = 2.4 \cdot 10^{-5}$ V.

Evaluation and results:

For b)
The graphs in Fig. 4 show that $U_H \sim B$ and that U_H increases with increasing transverse current I_Q.

Note:

Experimental proof of the proportional relationship $U_H \sim I$ may easily be obtained by measuring U_H for various I_Q (for constant field current I_B).

For c)
Negative Hall voltages are obtained for the setup *of current and field direction chosen in Fig. 2.* If the "right-hand rule" is used, we find that the conduction mechanism for silver is mainly effected by negative charge carriers.

Note:

In 1916, Tolman obtained certain proof that electrons are the charge carriers in metals.

For d_1)

Evaluation in accordance with (1) and (2):
$R_H = 7{,}74 \cdot 10^{-11}\ m^3 \cdot C^{-1}$
$n = 8{,}06 \cdot 10^{28}\ m^{-3}$
For d_2)
$R_H = 7{,}45 \cdot 10^{-11}\ m^3\ C^{-1}$
$n = 8{,}37 \cdot 10^{28}\ m^{-3}$
Note:

Theoretical value: $R_H = 8.9 \cdot 10^{-11}\ m^3\ C^{-1}$

$n = 6.6 \cdot 10^{28}\ m^{-3}$

(atoms density $5.8 \cdot 10^{22}\ cm^{-3}$)